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ENHANCED UNDER FREQUENCY LOAD SHEDDING (UFLS) SCHEMES PERFORMANCE IN SABAH GRID SYSTEM

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ENHANCED UNDER FREQUENCY LOAD SHEDDING (UFLS) SCHEMES PERFORMANCE IN SABAH GRID SYSTEM

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A project report submitted in partial
fulfillment of the requirement for the award of the
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I hereby declare that the work in this project report is my own except for quotations and summaries which have been duly acknowledged

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ABSTRACT

In the last five decade, peoples can survive successfully even without the existing of electrical energy. Nowadays, electricity is one of the important aspects for human being to run their daily life. Generation capacity should increase in proportion to the increase of its loads, but, if there are sudden changes in the system generation capacity through loss of generator or due to line tripping can produce severe generation-load imbalance. Under frequency load shedding scheme is implemented to restore power system frequency stability if system frequency drops below the operational set point during major disturbance such as lost of generation. Different countries/utility companies have their own philosophies in implementing the under frequency load shedding scheme. Generally, it is based on country/utility requirements, e.g. the overall power system network and the country's demographic. As the main power utility in Sabah, Sabah Electricity Sdn Bhd (SESB) takes the responsibility to ensure that the daily operation are always operated in a reliable and secure condition in supplying power to the consumers. This project presents the principles and implementation of the under frequency load shedding (UFLS) scheme and conducted through simulation of 150,000 test bus-system in Sabah Grid System. The performance of the existing schemes under various conditions of disturbance were compared and analyzed. All the simulation works were performed using Siemens PTI software Power System Simulator for Engineering (PSS/E).

ABSTRAK

Dalam lima dekad kebelakangan ini, masyarakat masih mampu meneruskan kehidupan walaupun tanpa kewujudan tenaga elektrik. Kini, bekalan elektrik merupakan salah satu aspek penting bagi manusia dalam melalui kehidupan harian. Kapasiti penjanaan seharusnya bertambah sejajar dengan peningkatan beban, namun, sekiranya berlaku perubahan drastik dalam kapasiti penjanaan akibat daripada kehilangan penjana kuasa ataupun talian terpelantik boleh mengakibatkan ketidakseimbangan penjanaan – beban yang ekstrem. Skim *Under Frequency Load Shedding* dilaksananankan untuk mengembalikan kestabilan frekuensi sistem kuasa sekiranya frekuensi sistem jatuh di bawah paras pengoperasian bilamana berlakunya gangguan teruk seperti kehilangan penjanaan. Pelaksanaan skim *Under frequency load shedding* ini adalah berbeza-beza bagi setiap negara/utiliti mengikut falsafah masing-masing. Umumnya, ia bergantung kepada kesesuaian sesuatu negara/utiliti, sebagai contoh rangkaian sistem kuasa menyeluruh dan bentuk mukabumi sesebuah negara. Sebagai utiliti kuasa yang utama di Sabah, Sabah Electricity Sdn Bhd (SESB) bertanggungjawab dalam memastikan operasi harian sentiasa beroperasi seperti yang diharapkan dan dalam kondisi yang selamat dalam membekalkan kuasa kepada pengguna. Projek ini membentangkan prinsip-prinsip dan pelaksanaan skim *Under Frequency Load Shedding* yang dilakukan menerusi 150,000 sistem-bas ujian di Sistem Grid Sabah. Prestasi skim yang sedia ada menerusi pelbagai kondisi gangguan telah dibandingkan dan dianalisa. Semua kerja simulasi dilakukan menggunakan perisian Siemens PTI iaitu Power System Simulator for Engineering (PSS/E).

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CHAPTER 1

INTRODUCTION

1.1 Project Background

In the last five decade, peoples can survive successfully even without the existing of electrical energy. Nowadays, electricity is one of the important aspects for human being to run their daily life. One of the techniques that can be used to generate electricity is by burning huge fossil fuels that will lead to the end of source for a number of years ahead. In order to overcome the source shortage, a lot of countries search for other source such as by using wind power, wave power, hydro power, solar power, geothermal energy and also nuclear energy.

Basically, power system network generation capacity should increase in proportion to the increase of its loads, but, if there are sudden large changes in the system generation capacity through loss of generator or key inter-tie due to line tripping can produce severe generation-load imbalance. In those cases the power generation capacity decreases but the load demand remains constant and causes rapid system frequency decline. If other generators are unable to supply the power needed, then the frequency begins to decline further.

With a small disturbance, the frequency decay rate will be low and the turbine governor will quickly raise the steam or water to the turbine to restore the frequency, provided the system has sufficient spinning reserve [4]. However, if the disturbance is large, because of the definite time response of the turbine speed-governor, spinning reserve provide little assistance in short time recovery and the frequency may fall to a dangerous value before the turbine governor fully operated.

The electricity generation in Sabah is under the responsibility of Sabah Electricity Sdn Bhd (SESB) utility company. SESB is the one and only power utility industry in Sabah with core activities of electric generation, transmission and distribution to over 1 million customers throughout Sabah region. The highest load demand recorded for Sabah is about 830 MW which includes all main regions in west coast and east coast of Sabah. As the main utility, SESB is responsible to ensure that the daily operation are always is a reliable and secure condition in supplying power to the consumers.

Any minor as well as major disturbances need to be handled and solved immediately to avoid system collapse and maintain the supply. However, as a power utility company, SESB are not excluded from power supply problems such as insufficient generation, equipment and protection failure, over voltage and also under frequency issues.

The decrease in system frequency, which occurs very rapidly, if left unattended, will lead to system collapse. in this case, some immediate pre-selected load shedding provides a path for the power system to restore the frequency back to its normal value[1-2]. To stop further declining of system frequency, which may lead to total system collapse, the fastest way is temporary disconnect a portion of electrical load from the system known as under frequency load shedding (UFLS).

Under-Frequency load shedding (UFLS) is defined as a coordinated set of controls, which results in the decrease of electrical loads in the power system. This set of possible corrective actions aims at forcing the perturbed system to a new equilibrium state (balancing the load and generation and thus maintaining system frequency within nominal range) [2].The main objective of UFLS is to shed an appropriate amount of load for quick recovery of system frequency to its nominal value.

UFLS as a coordinated set possible corrective actions aims at forcing the perturbed system to new equilibrium state [2]. It is a set of corrective actions to balance between load and generation; thus, maintaining network system's frequency within nominal range. Under frequency load shedding is implemented to restore power system frequency stability if system frequency drops below the operational set point during major disturbance such as lost of generation. Different countries/utility companies have their own philosophies in implementing the under frequency load shedding scheme.

For SESB itself, the existing UFLS scheme has been implemented since 2005 and reviewed annually depends on system requirement. Basically, there are 6 stages of UFLS in SESB network system where the 1st stage is set at 49.5 Hz with 2 seconds time delay. The scheme usually reviewed based on the annual increment on the system demand and power consumptions.

As the demand and consumption of electricity keep on changing due to the increase population and the high number of developing consumer in this company, a smart defence system is required to be installed in the whole system for a better planning and delivering of electrical power generation. Hence it is hope that the revised schemes propose in this study could be a contribution to reduce the power supply interruptions which can lead to system collapse and also provide a good principle of effective operation and help to maintain the quality of electricity supply in this region.

1.2 Problem Statements

Power systems are designed and operated so that for normal system condition, including a defined set of contingency conditions, there is adequate generating and transmission capacities to meet the load requirements. However, there are economic limits on the excess capacity designed into system and contingency outages under which a system may be designed to operate satisfactorily. Frequent disturbance and interruption are normal in SESB or even in other power utilities, but the most critical situation arises when it comes to total blackout for that region. This event has been experienced by the Sabahan on the 30th April 2012 due to some protection issues. Although the scheme has been reviewed for several times for system defense improvement but still there are some technical issues regarding the effectiveness of the scheme.

As the demand and consumption of electricity keep on changing due to the increase population and the high number of developing company in this company, a smart defence system is required to be installed and reviewed accordingly in the whole system for a better planning and delivering of electrical power generation. Hence it is hope that the revised schemes of UFLS propose in this study could be a contribution to reduce the power supply interruptions which can lead to system collapse and also provide a good principle of effective operation and help to maintain the quality of electricity supply in this region.

1.3 Project Objectives

The major objectives of this project:

a) To analyze the performance of the existing under frequency load shedding schemes in SESB
b) To identify the weaknesses and disadvantages of the existing defence schemes based on previous disturbance events.
c) To revise and update the existing under frequency load shedding schemes in order to improve the reliability and security system for Sabah Grid.

1.4 Project Scopes

This study will only focus on reviewing the under frequency load shedding (UFLS) scheme based on the total load demand for Sabah Grid as update of June 2012. The existing UFLS scheme will be reviewed and revised in order to improve the defence system for Sabah Grid. Power System Simulator for Engineering (PSS/E ver.32) software will be used to simulate and conduct the system study based on the relevant input data.

This analysis is carried out with the following objectives, firstly, to ensure that Sabah Grid Code requirement with respect to severe system is satisfied following loss of the largest generating unit. Secondly, sufficient load shedding quantum is provided to ensure that system frequency recovers to the required value following unsecured contingencies [9]. The system develop in this project has been limited to Sabah region only through Sabah Electricity Sdn Bhd (SESB) data without any segmentation of countries and localization.

1.5 Thesis Outline

The subsequent chapters of the thesis are organized as follows:

Chapter 1 highlights on the background of load shedding and the implementation of under frequency load shedding (UFLS) scheme in electrical power system, especially in Sabah Electricity Sdn. Bhd. The objectives of this research are stated clearly in this chapter. The literature review of this project will be discussed in Chapter 2. This chapter will give the details about the basic theory of application and the development of under frequency load shedding scheme. Some of the previous studies and researches are shown in this chapter.

Chapter 3 will discusses and elaborates the project procedure starting from reviewing the whole system of Sabah Grid then finally revising the existing UFLS scheme with the new proposed scheme. The basic simulation procedure will be discussed in this chapter. Chapter 4 shows the results and further data analysis. The simulation results using PSS/E software by implementing the UFLS schemes through Sabah Grid system is showed and discussed here.

Chapter 5 presents the project discussions, conclusions and recommendations. The conclusions and some future recommendations are also discussed in this chapter.

1.6 Summary

This chapter of this thesis discusses about the introduction for the whole project. Firstly, the principle and concept of the under frequency load shedding were introduced. Next, the problem statement is discussed. Then, the next part is about the objectives and scopes of the project. Lastly, the thesis outline is discussed which will give an overview for the reader about the thesis.

CHAPTER 2

LITERATURE REVIEW

2.1 Power System Operation

Electric Power Systems can be defined as the transformation of other types of energy into electrical energy and the delivery of this energy to the points of consumption [6]. The basic power system is the combination of 3 major components which are generation (energy conversion), transmission/distribution and load/consumption as shown in Figure 2.1 below. When the basic power systems are connected together through transmission or distribution lines/equipment, they become an interconnected power system.

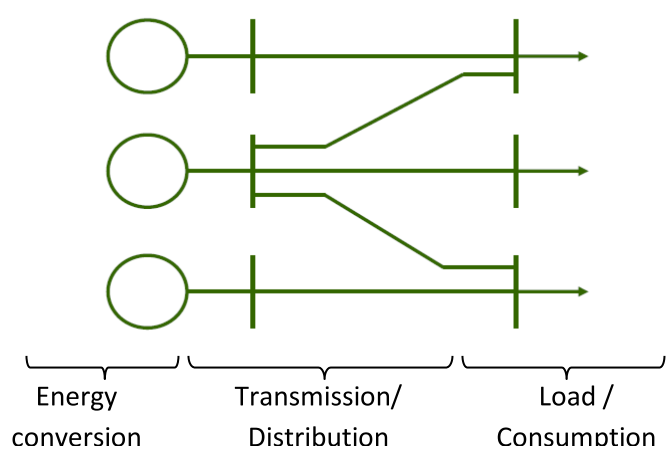

Figure 2.1: Basic configuration of power system

The objective of power system operation is to keep the electrical flows and bus voltage magnitudes and angles within acceptable limits (in a viable region of the state space), despite changes in load or available resources. Security may be defined as the probability of the system's operating point remaining in a viable state space, given the probabilities of changes in the system (contingencies) and its environment (weather, demand, etc.)

2.1.1 Dynamic and Stability

In power system, dynamic is about the study of the behaviour (trajectory, response and movement) of the power system states and controls following disturbances. Dynamic describes the behavior, i.e., always changing or not remaining the same which sometime can be large and small. Since the power system is dynamic following a disturbance, states and controls will change (will move) according to certain trajectories.

Stability is the ability of the states and controls to return to certain operating equilibrium following the disturbance. Stability describes the consequence of the dynamic behavior, i.e., its ability to regain a state of equilibrium after a certain dynamic changes. Frequency stability concerned with the ability of a power system to maintain steady frequency within a nominal range following a severe system upset resulting in a significant imbalance between generation and load.

2.1.2 Reliability and Security

The degree of performance of the elements of the bulk electric system that results in electricity being delivered to customers within accepted standards and in the amount desired. Reliability may be measured by frequency, duration, and magnitude of adverse effects on electric supply. Electric system reliability can be addressed by considering two basic functional aspects of the electric system, which are adequacy and security.

System security is a subset of power system reliability which comprises of two components which are related to the time-frame of power system dynamics:

- Adequacy
  - the ability of the power system to supply the aggregate electric power and energy requirements of the customers within component ratings & voltage limits, taking into account planned and unplanned component outages.

- Security
  - The ability of the system to withstand specific sudden disturbance such as unanticipated loss of system components.
  - Power system security is the ability of a system to withstand without serious consequences any one of pre-selected list of "credible" disturbances ("contingencies")

2.1.3 Contingency Analysis

Contingency analysis is the subject about evaluating adequacy and security through software application to give an indication of what might happen to the power system in the event of unplanned (or unscheduled) equipment outage. In power system operation, the results of contingency analysis are used to operate the system defensively where load flow program is used extensively for evaluating adequacy. Two components of contingency analysis are:

- Steady state security analysis
  - Determine state of the following disturbance when transients have settled by using load flow calculations.

- Dynamics security analysis

- Disturbances such as line outages or loss of generation usually begin with transient changes in line flows and voltages before some steady-state condition are reached.
- Contingency analysis for evaluating the network during transient is known as dynamic security analysis.

2.2 Under Frequency Load Shedding (UFLS)

Under-Frequency load shedding (UFLS) is defined as a coordinated set of controls, which results in the decrease of electrical loads in the power system. This set of possible corrective actions aims at forcing the perturbed system to a new equilibrium state (balancing the load and generation and thus maintaining system frequency within nominal range) [2].

UFLS is the last resort for tackling serious frequency declines in power systems. Therefore, when power systems are faced with huge disturbances or severe power deficiencies, the ability to maintain the power balance and stabilize the frequency is directly related to the UFLS strategy employed. For a good UFLS strategy, the following requirements should be met:

- The frequency decline can be restrained and the normal frequency value can be restored.
- The time spent in the frequency recovery should be minimized, and frequency overshoot or hovering should be avoided.
- The load amount to be shed should be minimized.
- The overall cost of the UFLS strategy should be as low as possible.

Historically, the traditional static load shedding scheme has been the most widely used scheme, as it was simple and it did not require complicated relays for implementation. The traditional scheme sheds certain amounts of load in several steps when the system frequency falls below certain thresholds. The value of thresholds and relative amounts of load to be shed are decided off-line, on the base of experience and simulations.

2.3 UFLS Methods

After years of development and research, UFLS schemes can be divided into three categories: traditional method, semi-adaptive method and adaptive method [1-3]. At present, the most widely used UFLS scheme is the traditional scheme [1], but this off-line setting scheme may easily lead to over-cut or owes-cut, and miss the best time for load shedding. Semi adaptive method, monitoring the rate of change of frequency in the first step of load shedding [2], has better selectivity than the traditional method when the active power shortfall is small.

2.3.1 Traditional Method

- In the traditional approach, when the frequency is lower than the first setting value, the first level of load shedding will be implemented.
- If the frequency continues to decline, it is clear that the first load shed amount is insufficient. When the frequency is lower than the second setting value, the second stage of load shedding will be implemented.
- If the frequency continues to decline, the further load shed stages will be activated until the normal frequency value is restored. However, the load amount to be shed is determined in the case of serious events.
- Therefore, when the frequency declines to its first shed level, the load that is shed is often excessive for the particular event.

2.3.2 Semi-adaptive Method

- The half adaptive approach is similar to the traditional approach to some extent. However, the specific amount of load to be shed is determined in terms of the measuring value of the rate of change of frequency (ROCOF).
- The semi-adaptive *scheme [9]* provides a step forward. In fact, it measures df/dt when a certain frequency threshold is reached.
- According to that value, a different amount of load is shed. In other words, this scheme checks also the speed at which the threshold is exceeded: the higher this speed is, the more load is shed.
- Usually, the measure of the ROCOF is evaluated only at the first frequency threshold, the following ones being traditional.

2.3.3 Adaptive Method

- The next improvement in load-shedding is the so called the adaptive method, an improved and yet more reasonable algorithm which makes use of the frequency derivative and is based on the *System Frequency Response* (SFR) model developed in [10].
- The frequency response model is built on the basis of the frequency differential equation and the rotor motion equation in this approach. Based on the variations of frequency, the amount of load to be shed by the adaptive approach can be determined more accurately.
- This model is obtained from the complete block diagram representation of a generic generating unit, along with its governor. A reduced order SFR model for the whole electrical system can be obtained on the basis of commonly adopted hypotheses [11].

- From the reduced order SFR model it is possible to obtain a relation between the initial value of the ROCOF and the size of the disturbance P_{step} that caused the frequency decline. This relation is:

$$\frac{df}{dt}\Big|\, t = 0 \qquad (2.1)$$

2.4 Power System Simulator for Engineering (PSS/E)

Power System Simulator for Engineering (PSS/E) is a software tool used for electrical transmission networks. It is an integrated, interactive program for simulating, analyzing, and optimizing power system performance and provides probabilistic and dynamic modeling features. Since its introduction in 1976 it has become the most widely used commercial program of its type. The probabilistic analyses and advanced dynamics modeling capabilities included in PSS®E provide transmission planning and operations engineers a broad range of methodologies for use in the design and operation of reliable networks.

Since its introduction in 1976, the Power System Simulator for Engineering tool has become the most comprehensive, technically advanced, and widely used commercial program of its type. It is widely recognized as the most fully featured, time-tested and best performing commercial program available. PSS®E is an integrated, interactive program for simulating, analyzing, and optimizing power system performance. It provides the user with the most advanced and proven methods in many technical areas, including:

- Power Flow
- Optimal Power Flow
- Balanced or Unbalanced Fault Analysis
- Dynamic Simulation

- Extended Term Dynamic Simulation
- Open Access and Pricing
- Transfer Limit Analysis
- Network Reduction

2.4.1 Power Flow Analysis

Power flow module is widely recognized as one of the most fully featured, time-tested and best performing commercial programs available for power systems analysis. Over 30 years of commercial use and user-suggested enhancements have made the PSS®E Power Flow base package comprehensively superior in analytical depth, modeling and user convenience and flexibility.

- User-switchable choice of five solution methods including Newton-Raphson (full, decoupled, fast decoupled), Gauss-Seidel, and modified Gauss-Seidel
- Inertial and governor power flow redistributes generation after major load or supply changes
- Standard and complex contingency analysis and transfer limit calculations
- Automatic corrective actions for improving system responses
- System reliability calculations
- Simulated generator economic dispatch or participation factors
- Generator reactive capability curves
- Extensive load modeling capabilities

2.4.2 Dynamic Simulation Analysis

PSS/E Dynamic Simulation module is a versatile tool to investigate system response to disturbances that cause large and sudden changes in the power system. The dynamic simulation module employs a vast library of built-in models for modeling different types of equipment, and with capability to create user defined models of any complexity. Several of the tey features of the PSS®E dynamic simulation tool are:

- Time tested and robust algorithm that has been used by utilities all over the world.
- A comprehensive built-in library of dynamic simulation models to model equipment.
- Ability to create any disturbance such as, faults, generator tripping, motor starting or loss of field.
- Ability to carry out extended term simulation. This feature allows users to study long term effects such as frequency deviation as affected by prime mover response and voltage changes caused by protective equipment; and yet minimize computer time by providing a variable step integration technique.

The paper from B. Delfino, A. Morini, P. Scalera and F. Silvestro has examined the current situation and the perspectives for under frequency load-shedding. Several schemes have been investigated: from traditional approaches based on frequency thresholds to semi-adaptive methodologies based on frequency its derivative [7]. A fully adaptive technique has been also used because of its potential interest in the current context of deregulation. The diagnosis phase previously mentioned and usually performed by means of frequency measurements can be improved by including the Rate of Change of Frequency (ROCOF). This value has the meaning of speed at which the frequent y is declining. By measuring the speed at which a certain frequency threshold is reached it is possible to estimate the danger of the current contingency and so to provide different load-shedding alternatives depending on the value of df/dt [11].

The next improvement in load-shedding is the so called adaptive method which makes use of the frequency derivative and is based on the *System Frequency Response* (SFR) model developed in [10]. This model is obtained from the complete block diagram representation of a generic generating unit, along with its governor. A reduced order SFR model for the whole electrical system can be obtained on the basis of commonly adopted hypotheses [11]. From the reduced order SFR model it is possible to obtain a relation between the initial value of the ROCOF and the size of the disturbance P_{step} that caused the frequency decline.

UFLS schemes have been applied to power systems to maintain system stability during generation load mismatch. Static studies are relatively simple to be performed and implemented. However, according to the results obtained through dynamic simulations, static studies could not provide the optimized settings [4]. It is shown that using appropriate dynamic modeling, load shedding algorithm performance could be optimized. While system restructuring is reducing power system reserve margins and endangering system stability, optimization of load shedding scheme using appropriate dynamic modeling become more important.

In order to analyze effects of dynamic modeling in load shedding schemes, four different types of modeling have been studied. The two first methods consider the whole system as a single element. Governor effect is considered for the 2"d algorithm as well. For the next two schemes the power system is modeled in its distributed form consisting of different generation sources located at different places and connected to each other by the transmission system. For the 3rd algorithm system load is considered as a global load, while for the 4Ih algorithm system load at each bus is modeled separately [8].

The optimization of a load shedding system was considered. A projected gradient method with analytic expressions for the partial derivatives was applied to a model of the actual Israeli power system. It was shown that by optimizing the loads of the different stages the overall performance of the system can be improved. Similar results can be obtained for the delays that are associated with each stage. The optimization algorithm leads to a local minimum that is strongly dependent on the initial guess. To obtain a global minimum, or, viewing the process as design problem, a good setting, one has to search over some typical initial guesses. Second order gradient methods, which are currently implemented, are believed to circumvent this problem, at least partially.

A new concept of adaptive under-frequency load shedding plan was presented in the paper by M. Parniani and A. Nasri. Effects of different generator parameters on the system frequency behavior after a disturbance were first investigated to set the basic concepts for the plan. The new adaptive load shedding scheme uses the rate of frequency decline in addition to the frequency signal in a centralized manner. The amount of overload is calculated from df/dt measurement data. Load shedding plan is then determined such that mean system frequency as well as frequencies of all generators are maintained within the safe margin, and at the same time unnecessary load disruption is avoided [3]. Performance of the proposed method versus a few traditional schemes is demonstrated through dynamic simulations on New England test network.

The majority of adaptive under frequency load shedding schemes are very dependent on an active power imbalance determination, based on a measurement of the initial frequency first time derivative. As this is difficult to perform, it is reasonable to attempt to avoid having to calculate the imbalance. Therefore, an approach to load shedding is used in this paper by U. Rudez and R. Mihalic, which is based on forecast of the system frequency response, using the frequency second time derivative as a source of information.. According to the results and nature of the presented methodology, it might be considered as a suitable option for the actual implementation in the EPS. Namely, the UFLS protection should be updated in order to harvest the improvements in computer and communication technologies also in the field of under frequency EPS protection.

The paper from J.A. Laghari, Hazlie Mokhlis, A. B. Halim Abu Bakar and M. Karimi proposed new intelligent under frequency load shedding scheme for islanded distribution network. From the simulation results, it can be observed that proposed UFLS scheme estimates the amount of load to be shed according to disturbance magnitude. The fuzzy logic load shedding controller (FLLSC) intelligently distinguishes between event based and response based cases and estimates power imbalance to shed the load. Proposed method can prevent the frequency drop by shedding optimal load in order to maintain the system stability. In one glance, this algorithm can improve and enhance the system frequency response.

Several studies from IEEE members proposed a fuzzy based under frequency load shedding strategy to shed optimum loads in an islanding mode to stabilize the system frequency. Proposed UFLS strategy is based on frequency and df/dt information. Fuzzy logic load shedding controller (FLLSC) uses these values as input and intelligently estimates the power imbalance during load disturbances. FLLSC after estimating the power imbalance sends this value to load shed controller module (LSCM) for shedding loads according to load priority. Combination of event based and response based method are used for applying load shedding scheme in the network. Standard frequency pick value to begin load shedding scheme is 49.5Hz [15]. FLLSC calculates the value of fall in frequency and disturbance magnitude. If frequency value is less than 49.5Hz, load shedding strategy will operate to shed the load to stabilize frequency.

Load shedding techniques are developed to prevent frequency decline due to over loading in the system. An UFLS scheme was adopted to improve the system stability and security by enhancing the frequency and voltage response of the system on occurrence of contingency in the power system. The research by J. A. Laghari, A. Shahriari and M. M. Aman developed the load shedding scheme based on frequency and ROCOF for islanded distribution network. Also, it used the response based and event based method to improve the frequency response. The UFLS scheme disconnected the required load according to the load prioritization. The proposed method considers the load shedding without depending on overload location.

In recent years, modern system analysis software programs have been designed as a component of a larger power management system in order to perform system analysis using real-time data. In addition, techniques such as Neural Network (NN), Generic Algorithms (GA), Simulated Annealing (SA), Fuzzy Logic (FL), Expert Systems (ES), etc, have emerged in the field of power systems offering more effective problem solving, knowledge representation and reasoning, search, planning and action, for some highly non-linear problems, which often failed be solved using conventional techniques [6]. In addition, power system modeling and simulation software tools have been significantly improved to perform various system analyses from a simple load flow study to more advanced studies such as transient stability analysis.

Although the adaptive scheme which takes into account the frequency derivative has been presented and improved in many literatures [3-5], the traditional UFLS schemes based on frequency thresholds [6] are implemented extensively in China [7, 8]. This kind of UFLS scheme is composed of several stages. Under the UFLS scheme, the percentage of load is assigned at each stage for some specific feeders in the power system [9]. The corresponding feeders would be disconnected when the frequency reaches the thresholds and the percentage of load shed at each stage is not a constant since the load on every feeder varies with time, weather, and state of economy. Under some circumstances, the load shed during the UFLS procedure would be insufficient or excess for system frequency to recover within the normal range. MU Tao, WEI Zhen, GONG Cheng Hu and HUANG Zhi Gang introduce the concept of the feasible region of UFLS (FROUFLS) which could force the perturbed system to a new equilibrium state with acceptable frequency. The proposed FROUFLS can make sure that the load on the feeders at every stage of UFLS is appropriate.

2.5 Summary

This chapter has discussed about the literature reviews for this project. The short review on power system definition and operation is discussed. The purposes and conditions for the under frequency load shedding process as well as several methods used is also discussed. Then, the introduction and application of Power System Simulator for Engineering (PSSE) software to be utilized for this project is discussed. A few previous researches are mentioned for UFLS schemes and methods. Lastly, the comparison of UFLS methods is discussed.

CHAPTER 3

METHODOLOGY

3.1 Basic UFLS schemes

Frequency is a reliable indicator of generation deficiency or overload condition. A load shedding action is realized by an under-frequency relay, which issues a trip signal to the circuit breaker when the system frequency falls under the relay's frequency setting. The tripping is done in several stages comprising certain amount of load until the normal frequency is restored. Load shedding schemes can be grouped into three main categories: traditional, semi adaptive and adaptive [5].

The traditional scheme is the most simple and used by most utilities. It sheds certain amount of load when the system frequency falls below certain threshold. The semi-adaptive method measure the rate of change of frequency (ROCOF) when the system frequency reaches certain threshold. The adaptive method used model obtained from the complete generating unit, along with its governor. In formulating a load shedding scheme several criteria have to be considered, which includes [4]:

i. Power system characteristics

In implementing under frequency relay load shedding scheme, it is necessary for power system engineers to have some knowledge on the behavior of system frequency when load exceeds the generating capacity, and when the systems recovers from such situation.

ii. Maximum anticipated system overload

Typically, UFLS schemes are designed to protect for maximum overload situation. It should be able to provide coverage during a substantial generation loss. A scheme is designed for a 50% - 100% overload, but probably would not work for 0% - 50% overload situations. The anticipated overload (L) can be determined by the following equation [6, 7]:

$$L = \frac{Total\ Remaining\ Generation - Total\ Load}{Total\ Remaining\ Generation} \tag{3.1}$$

iii. Determination of maximum load to be shed

The amount of load to be shed should be sufficient enough to restore system frequency to its normal or close to its nominal value, within 1 Hz from the rated frequency [8]. The total amount of load shed can be determined using the following equation [6, 7]:

$$LD = \frac{\frac{1}{1+L} d(1-\frac{f}{50})}{1-d(1-\frac{f}{50})} \tag{3.2}$$

Where;

LD – total load to be shed

L – per unit anticipated overload

f – Minimum permissible frequency

d – load reduction factor

iv. Number and size of load shedding steps

The number and size of load shedding steps normally related to maximum load to shed. The larger amount of load to shed, the larger the number and size of load shedding steps implemented. Limiting the steps to a small number between 3 to 6 would simplify relay coordination and the amount to be shed could be minimized [4]. However, there are also some utility companies employed 8 and up to 15 steps.

v. Frequency Level and relay settings

The frequency steps depends on the system nominal operating frequency range, the operating speed, accuracy of frequency relays and the number of load shedding steps. The first step frequency should be just below the system normal operating frequency or the frequency at which the system could continue to operate [4]; for example, for 50 Hz system, the first load shedding step could be initiated at 49.5 Hz. The frequency level should be selected to avoid shedding for minor disturbance or sudden frequency deviation due to sudden changes of loads from which the system able to recover on its own.

vi. Location of the under frequency load shedding relays

Load shedding or under-frequency relays are usually installed at distribution stations, where predetermined loads can be disconnected. For large systems, the UFLS relays should be installed throughout the system to avoid heavy power flows and undesirable islanding effect [8]. To maintain an acceptable system power flow, the best possible area where load should be shed is the area which is close to the lost source of power.

Different countries/utility companies have their own philosophies in implementing the load shedding scheme. The designing of the scheme is based on their requirements, the overall power system network, country's demographic and etc. Currently, most of the power utility companies employed a static off-nominal UFLS scheme including Sabah Electricity Sdn Bhd. UFLS schemes have been installed in SESB to disconnect load with respect to falling frequency in the event of a major loss of the largest generation unit [9].

Frequency is a reliable indicator of generation deficiency or overload condition. A load shedding action is realized by an under-frequency relay, which issues B trip signal to the circuit breaker when the system frequency falls under the relay's frequency setting. The tripping is done in several stages comprising certain amount of load until the normal frequency is restored. Common practices by most utilities use 49.3Hz as the first frequency step and between 48.5 and 48.9 Hz for the last step [10].

The main motivation in UFLS scheme is to avoid the frequency deviating from its nominal value. Most rotating machine is designed for optimum performance at a specific frequency. Often, rotating machine cannot operate safely or effectively at more than a few percent below rated frequency. Continuous operation of steam turbines should be restricted to frequencies above 48.5 Hz. Operation below 48.5 Hz should be limited to very short periods of time [12].

3.2 UFLS Design Procedure

After the partial system collapse of April 2008, SESB implemented a 6-stage under frequency load shedding scheme of 400 MW in September 2008 based on a credible generation loss of 280 MW. The first UFLS schemes used in SESB system is listed in Table 1 [10]. The basic simulation tests were performed using the Power System Simulator for Engineering (PSS/E) software to determine the system frequency excursions. There are three tests simulated which can be summarized as follows [10]:

1. **Trip/drop unit tests without load shedding** –
   In this test the drop unit is performed based on the largest full block and half block combined-cycle power plant. In addition, the trip of the largest unit is also

tested. These tests have been carried out for all study years considering the spinning reserve requirements.

2. **Trip/drop unit test with load shedding scheme using the existing UFLS schemes -**

   In this test, the under frequency load shedding scheme as used by SESB were simulated.

3. **Trip/drop unit test with load shedding using proposed scheme/criteria** – In this test, a new under frequency load shedding scheme is proposed to arrest the frequency decay and its subsequent recovery.

3.2.1 System Behavior

Sabah Grid System is a unique utility system with various load duration curve which can be divided into 3 typical load patterns, Weekday, Saturday and Sunday. Each load pattern consists of 3 different load demand, peak load demand, medium load demand and light load demand. The typical load duration curve for Sabah Grid System is shown in Figure 3.1.

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